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interpretation of the physical processes from t[redacted]ensed data.

These topics are considered from perspectives [redacted]theory, field experiments, and analyses of the faithfulness and validity of models and simulations of these pr[redacted]sses. The research results are expected to contribute to improved models of boundary layer processes for visual[redacted]ion and field use through strong interactions with appropriate Army laboratory scientists.

2.2.3. Management of Atmospheric Informati[redacted] Providing useful atmospheric effects information to the soldier and decision maker is the focal point of the A[redacted]s atmospheric sciences effort. The information needs of each user may be very different. Furthermore, the infor[redacted]on must be in a form that is readily understood in light of the user's needs. At the same time, the path from [redacted] to information must have a fundamental scientific basis. The science issues behind the information manage[redacted]t include an ability to obtain data from multiple sources, friendly or adverse, quantitative and qualitative; fusing [redacted] data into a comprehensive representation of the present and future atmospheric state; understanding of the uncert[redacted]ies of the data and their effects on the application; and communicating the complex four dimensional [redacted]ospheric state in the language and application of the user. To accomplish the goals of information managem[redacted] improved computational methods are needed to assimilate and integrate the data, assess the atmospheric pres[redacted]and future state, and disseminate the user's needed information in a timely and effective manner.

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RESEARCH AREA 3
MATHEMATICAL SCIENCES

3.0. Mathematical and computational methods pervade research, development, testing, and evaluation problems encountered by the Army. Furthermore, increasing demands are being placed on research in the mathematical sciences because of their fundamental role in the analysis and modeling issues that arise in military science, engineering and operations. Although these problems are often and quite naturally stated in terms of their system or operational implementation, their solutions are usually dependent on a number of mathematical subdisciplines. For example, some promising approaches to computer vision for automatic target recognition (ATR) require research in a wide range of areas including constructive geometry, numerical methods for stochastic differential equations, Bayesian statistics, tree structured methods in statistics, probabilistic algorithms, and distributed parallel computation. Another example is furnished by simulation. Here improvements depend on a large number of research areas including large scale scientific computing and real time computing for embedded systems. Similarly, recent research on dynamical systems, control theory, logic and concurrency is being applied to the extraction and verification of digital control programs for continuous systems.

In this announcement, the Army Research Office areas of interest will be described to the potential researcher and user mainly by means of research topics within mathematical sciences. This procedure has the benefit that our program managers can amplify the worth of their programs by funding research topics that have impact on many different problems.

To be able to respond to the increasing demands on the mathematical sciences, the ARO attempts systematically to advance fundamental knowledge that focuses on the needs of the Army. To accomplish this objective, the Division supports extramural basic research in the five areas that follow. A program represents each of these five areas. The research supported by the Division does not cover all or even the majority of topics in these areas. Rather, it covers only certain sub areas that are of strategic importance for the Army. Programs typically have two to four foci. There are unavoidable overlaps between programs. The sub disciplinary boundaries within the Division and the disciplinary boundaries in the ARO are not rigidly drawn and there is strong interest in and appreciation for multidisciplinary research in which the mathematical sciences play a major role.

Potential offerors are encouraged to contact the appropriate Technical Point of Contact (TPOC) for preliminary discussions on their ideas. The TPOC may invite the offeror to submit a preproposal.

3.1. Modeling of Complex Systems. The Modeling of Complex Systems Program is a program of fundamental mathematics-oriented research the objectives of which are to develop quantitative models of complex phenomena of interest to the Army, especially those for which current models are not based on first/basic principles, and to develop new metrics, preferably those based on first/basic principles, for these models. The complex phenomena of interest to the Modeling of Complex Systems Program include (1) physical phenomena, (2) abstract phenomena in information theory and networks and (3) behavioral phenomena. Complete and consistent mathematical frameworks for the modeling effort are the preferred context for the research, but research that does not take place in such frameworks can be considered if the phenomena are so complex that the frameworks are not feasible. Metrics are part of the mathematical framework and are of great interest. Traditional metrics, when they exist, often do not measure the characteristics in which observers in general and the Army in particular are interested. For many complex phenomena, new metrics need to be developed at the same time as new models. Just as is the case for the modeling effort, these metrics should preferably be in a complete mathematical framework. The research in modeling of and metrics for complex phenomena of interest to the Modeling of Complex Systems Program may include numerical/computational work as a subordinate component. However, research that focuses mainly on numerical/computational issues should be directed to the ARO Computational Mathematics Program. The investment in the Modeling of Complex Systems Program is in the following seven areas.

3.1.1. Advanced Complex Materials for Structures, Armor and Sensors. The analysis, design and manufacture of advanced materials is an interdisciplinary area in which the basic principles are often known. However, the current models for meso and macro behavior of materials are often not based on these principles because implementation of the basic principles in the models results in inordinate complexity and because principles on intermediate levels are not well known. The Modeling of Complex Systems Program supports research oriented toward optimizing properties or performance characteristics of highly nonlinear materials, including advanced composites for structures and armor and smart materials for sensors. Lightweight, high-strength structural components, including advanced composites, contribute to attaining mobility and protection requirements for U.S. Forces (as well as to the fuel efficiency and safety of the U.S. automobile fleet). Advanced composites are challenging to analyze and design because of the presence of many interacting length scales. Smart materials, the functional ingredients of actuators, sensors and transducers that have a load- or field-dependent (crystal or other) structure are of interest. Such materials may undergo a phase transformation when some mechanical, thermal, electrical or magnetic factor changes and vice versa. Advanced composites and smart materials are typically highly nonlinear. In seeking to understand the relationship between the microscopic and macroscopic length scales of these materials, fundamental issues in nonlinear modeling arise. The program invests in research on these fundamental issues, including development of basic equations and constitutive laws.

3.1.2. Inverse Scattering in Complex Media. Inverse scattering is of interest to the Army for detection and identification of landmines and unexploded ordnance with low false alarm rates. This is an area involving the interaction between the propagation of various types of waves in cluttered soils and the inverse problem of detecting location, shape and material properties of solid objects having various waveform signatures. Currently available techniques often have high false alarm rates, which impede mine clearance. Additional Army interests include electromagnetic sensing through cluttered battlefield atmospheres, including smoke, fog, flames, etc. Application of inverse scattering techniques for standoff detection of chemical and biological agents is of interest. One of the directions of research is that of creating models for currently unused sources of information, validating these models and integrating them into larger models or systems. Traditionally, imaging by ground-penetrating radar and by x-rays has utilized information only from singly scattered waves, that is, waves that are scattered by a collision with only one object and then return to the detectors. For such imaging, multiply scattered waves that arrive at the detectors create error, because they are erroneously presumed to have resulted from a single scattering event. However, multiply scattered waves contain information, not just error. Creating models that are able to access the information in multiply scattered waves is of considerable interest. Integrating these models into models/systems that also use the information in singly scattered waves is of interest. Research on multiple scattering in complex media includes research on models for utilizing other sources of information that are ignored by current models.

3.1.3. Modeling of Multiscale Objects and Functions. Representation of complex, multiscale/mulitresolution geometric objects and of complicated, often high-dimensional, abstract phenomena and functions is fundamental for Army, DoD and civilian needs in modeling of terrain, geophysical features, biological objects (including humans and their clothing), computational learning and many other objects and functions. Real-time visualization of huge terrain databases with glitch-free zoom-in/out cannot be achieved with current techniques. Progress in automatic target recognition, robotic vision, representation/compression of data in general and many other areas depends on advances in approximation theory. A key to achieving these goals is data compression at ratios and with accuracy that exceeds what is currently known. A multitude of variants of piecewise planar surfaces (including those on triangulated irregular networks or "TINs"), splines, multiquadrics, kriging, wavelets, neural nets and many other techniques developed in the past perform well on many types of data. However, none of these procedures are able to provide, without human intervention, representation of geometry and data with the accuracy and compression that is needed. To achieve such representation, new types of approximation theory appropriate for complicated multiscale/multiresolution surfaces and phenomena need to be developed. In these cases, the objects/functions being approximated are not consistent with the assumptions of classical approximation theory. Approximation theory research that results in highly compressed, loss-free or minimally lossy representation is of particular interest. Approximation theory for information flow and other abstract items in large communication and computer networks is an area of interest. The approximation theory developed under support of this program is expected to provide building blocks for computational geometry, pattern recognition, automatic target recognition and visualization systems. However, research that is focused on these areas rather than on approximation theory is beyond the scope of the Modeling of Complex Systems Program and fits best with the Image Fusion, Processing and Circuits Program of the ARO Computing and Information Sciences Division and with the Discrete Mathematics and Computer Science Program of the ARO Mathematical Sciences Division.

3.1.4. Nonlinear Dynamics for Communication. Enhanced capability in digital communication is recognized as a pivotal element in a modern economy and in national security. At present, digital communication is carried out mainly by linear devices, that is, by transmitters and receivers operating in the so-called linear regime. The option of creating digital communication systems based on transmitters and receivers operating in the nonlinear regime is already under investigation. One type of nonlinear behavior on which these transmitters, receivers and codes can be based is chaos, that is, the deterministic but complicated behavior of physical systems in which arbitrarily small changes in the input produce large changes in the output. The potential advantages of nonlinear digital communication devices include increased power and bandwidth efficiency, light weight, compactness, increased information-bearing capacity, greater number of channels, low-cost manufacturing, low probability of interception (LPI) and low probability of detection (LPD). The Modeling of Complex Systems Program is interested in the nonlinear modeling that needs to be done to create new, nonlinear transmitters, receivers and codes. Research in controlling chaos, which is inherently unstable, in ways suitable for these devices and codes is important. Investigation of the information theoretic and symbolic dynamic properties of the signals produced (for example, size of alphabets, grammatical constraints on symbol sequences and entropies) is of interest. This research should be carried out in the context that leads to simple, inherently nonlinear devices. However, the engineering design of such devices is outside the scope of the Modeling of Complex Systems Program and fits best with an appropriate program in the ARO Electronics Division. Soliton theory for fiber optics communication is an important area of research but is beyond the scope of the Modeling of Complex Systems Program.

3.1.5. Data Fusion in Complex Networks. Enhanced capability in distributed sensing by organized or self-organizing networks of large numbers of geographically dispersed sensors, often microsensors (acoustic, infrared, magnetic, etc.), of various modalities is increasingly recognized as a pivotal element in the ability of defense forces to accomplish their mission. Such networks are a potential replacement for landmine fields. Over the past generation, great progress has been made in research and development of low-cost sensing devices. When networks contain small numbers of sensing devices, issues of network organization and topology and issues of information processing can often be addressed in known scientific/engineering frameworks. However, when networks contain large numbers of sensing devices, issues of information flow and information processing are a challenge for which basic principles remain to be created. Such basic questions as how to measure "goodness" or optimality are still open. As the number of devices in distributed sensing systems increases from hundreds to thousands and perhaps millions, the amount of attention paid to information flow and processing must increase sharply. The Modeling of Complex Systems Program is interested in research on information flow and information processing in large, dynamic networks of sensors, primarily microsensors with limited capabilities and power. Development of metrics, preferably based on first principles rather than ad hoc, for measuring goodness is a topic of concern. Developing models (more likely nonlinear than linear) for linkage of scales in the information processing system for large networks is of interest. Research that leads to improved information processing under strong constraints on power and communication bandwidth is of particular interest.

3.1.6. Dynamics of Distributed Networks of Embedded Sensors and Actuators. Low-cost wireless networking, which is now becoming common, may be the catalyst that will lead to networking of embedded devices in Army and DoD sensing and weapons platforms, vehicles, soldiers and command and control organizations. The analysis and design of networks of embedded sensors and actuators will involve modeling at much deeper levels than that of bit flow. This design and analysis requires a solid mathematical foundation focused on issues of stability, robustness and performance not merely of the sensors and actuators but also of the people and objects in which they are embedded.

3.1.7.. Additional Areas of Opportunity. Behavioral modeling is an area of nonlinear modeling for which few basic principles are currently known. Research in this area is critical for military and civilian decision-making, training and rehearsal. The nonlinear modeling of information flow and other abstract issues in large communication and computer networks is of interest. Approximation theory research mentioned above under *Modeling of Multiscale Objects and Functions* may be a component of this modeling. Modeling information flow and other dynamics in large networks is important research that is required for information assurance, that is, for protecting networks from unforeseen catastrophes and from deliberate attack. Analytical procedures that provide new ways to "image" networks, such as "network tomography" (deduction of network topology or other network properties from measurements at a limited number of nodes and/or over a limited number of paths) will be required for the maintenance and protection of networks. The interests of the Modeling of Complex Systems Program include these areas and also include mathematics-oriented research for other complex phenomena of interest to the Army that may be proposed by researchers.

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3.2. Computational Mathematics. The Computational Mathematics program supports basic research on innovative, efficient and accurate numerical methods, optimization techniques and scalable scientific software tools. Since quantitative predictions based on most modern theories require extensive computation, new methods and tools are needed to assure that mathematical models can be translated into realistic simulations. Such simulations are needed to understand, design and optimize the solution to the more complex problems faced by the Army. The overall focus of the Computational Mathematics program is on algorithmic problems which arise with new applications and on the exploitation of common features from different application areas to define problem classes and develop general solution methods.

3.2.1. Numerical Methods. The primary interest in this subarea is on finding solutions to algorithmic problems associated with currently intractable computational problems and new applications. Among the barriers that need to be addressed are interacting subsystems, multiple scales and the effects of uncertainty. Different mathematical models at different scales may describe different parts of a numerical simulation. New methods are needed to couple different types of models, simplify the complexity of systems and accurately compute small-scale effects in a large-scale simulation without brute force. Algorithms need to be designed to take advantage of the mathematical structure of potential applications. It may be advantageous to develop stochastic algorithms for deterministic problems or deterministic approaches for stochastic problems. Rigorous analysis is needed to determine structure, predict algorithm performance and drive adaptivity. Design, control and optimization require that simulations be performed many times. To accelerate such repeated simulations, reduced order models and fast algorithms in core areas such as linear algebra, ordinary differential equations and partial differential equations become important. Considerable progress has been made on the numerical treatment of interfaces, singularities and difficult boundary conditions but new applications may generate new difficulties. Uncertainty arises in models, parameters and interactions among components. Systematic methods are needed to evaluate and quantify the effects of these and other sources of uncertainty.

3.2.2. Optimization. As computing power increases, optimization will replace trial and error as the approach of choice for the solution of DoD problems. Problems of interest to the Army in science, engineering and operations are usually large, nonlinear and global with many local minima. A single problem may contain continuous, discrete and integer variables. The primary interest in this subarea is in mathematically sound methods for solving such problems. The emphasis is on methods rather than specific applications. Rigorous mathematical analysis is an essential part of this effort.

3.2.3. Software Tools. As numerical computations become larger and more complex, non-numerical issues become important. Computers have different architectures, multiple processors and complex memory hierarchies. Data is distributed among multiple computers connected to each other over networks with different bandwidths. Without mathematical tools that map algorithms to architectures with minimal input from programmers and users, computation on such systems is very difficult. In addition, large-scale computations produce huge data sets. Thus tools are needed to extract useful information from such data sets and to present results in ways that are easily understood. Progress has been made in grid generation, adaptivity and load balancing but new applications may generate new problems. Some tools have been developed but are not widely used. Therefore it is important to determine why this is so and what can be done to make such tools more useful for programmers and users. This subarea overlaps with the Discrete Mathematics and Computer Science program.

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3.3. Stochastic Analysis, Applied Probability, and Statistics. The Stochastic Analysis, Applied Probability and Statistics Program supports critical Army needs in decision making under uncertainty.

3.3.1. Stochastic Analysis and Applied Probability. Army research and development (R&D) programs directed toward system design, development, testing and evaluation problems generate a need for research in the field of stochastic processes, including stochastic differential equations. Special emphasis is placed on research into methods for the analysis of observations from phenomena modeled by such processes and to numerical methods for stochastic partial differential equations. Research areas of importance to the Army in probability and its applications include stochastic optimization and approximation, stochastic control, large deviations, simulation methodology, spatial processes and image analysis. Ideas are needed from Markov random fields, renormalization of the state space, scaling of time, nonlinear stochastic analysis and infinite-dimensional stochastic differential equations. The techniques required include Brownian flows, infinite-dimensional stochastic processes driven by Poisson noise and Levy noise.

3.3.2. Statistical Methods. There is great interest in statistical methods for very large data sets or very small data sets, sampled from nonstandard, poorly understood distributions. The extraction of more information from small data sets requires improved methods for combining information from disparate sets, as in meta-analysis. Useful statistical models should be based on a thorough understanding of physical processes combined with sound statistical theory. Thus, it is important to integrate statistical procedures with scientific and engineering information about mechanisms as exemplified by a probabilistic methodology that describes the nature of the growth of cracks in different media and the associated statistical analysis. More research is required in several statistical areas including Bayesian methods, Markov random fields, cluster analysis, change point methods, and Markov chain Monte Carlo methods. It is important to bring novel statistical thinking into resource management and optimization in very large communication and logistics networks.

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3.4. Discrete Mathematics and Computer Science. As suggested by the title, the Discrete Mathematics and Computer Science Program supports Army needs in discrete mathematics and theoretical computer science.

3.4.1. Discrete Mathematics. The interests in discrete mathematics are the development and analysis of solution procedures for discrete problems in computational geometry, computational algebra, logic, network flows, graph theory and combinatorics. Specific areas of emphasis include robust geometric computation, solid modeling, multi-resolution methods, parallel and distributed computing and dynamic interactive visualization techniques. Other areas of interest include distributed algorithms for network flows, randomization in computing, computational algebraic geometry techniques for solution of polynomial systems, discrete methods for combinatorial optimization, symbolic methods for differential equations, mixed symbolic-numerical methods for applied problems, parallel symbolic sparse matrix methods, and algorithmic methods in symbolic mathematics arising in, for example, automated reasoning systems, mathematical logic and formal language theory.

3.4.2. Theoretical Computer Science. The interests in this subarea include fundamental issues in parallel computing such as advanced data structures for parallel architectures, parallel algorithms, graph theoretic methods applied to a parallel and distributed computation and models and algorithms for the control of heterogeneous concurrent computing. Also of interest is research on tools for the development of parallel algorithms and expert systems for computation and visualization of solutions to partial differential equations. Exploring fundamental techniques that optimize I/O communication is a research area of great strategic importance.

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3.5. Cooperative Systems The objective of this work-package is to study and take advantage of the combined power of collaborative systems pertaining to groups of robots and other complex systems. An example is the cooperative activity of robots or communication systems with changing relative topology in the battlefield. Research areas include the mathematical foundations of system theory, communication nets, the swarming phenomenon, game theory, large data set manipulation, decision-making, and data processing related to intelligent systems.

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RESEARCH AREA 4
ELECTRONICS

4.0 Electronics. Electronics is widely recognized as a key force multiplier, underpinning the Future Combat System, as well as the Objective Force as an essential means to achieve technological superiority. The U.S. Army Research Office's Electronics Division seeks to support scientific and engineering endeavors in research areas that possess the potential to define new electronic capabilities or to enhance future electronic performance. The Electronic research sub-areas are Solid State Devices, Optoelectronics, Quantum Electro-Magnetic Devices, Sensors and Detectors, Electromagnetics and RF Circuit Integration, and Terahertz Science and Technology. We invite proposals for research to advance our understanding of electronic devices, materials, and processes with a strong prospect for use in future Army technology.

Potential offerors are encouraged to contact the appropriate Technical Point of Contact (TPOC) for preliminary discussions on their ideas. The TPOC may invite the offeror to submit a preproposal or white paper.

4.1. Solid State Devices. This research area emphasizes efforts to establish a new and comprehensive base of knowledge for the electronic, photonic, acoustic and magnetic properties of solid-state materials, structures and devices. Functions such as very intelligent surveillance and target acquisition; command, control, and communications; electronic warfare; and reconnaissance, must be accomplished with the high data rates and real-time capability that are essential for these applications. To support the U.S. Army vision of Objective Force and Future Combat System of Systems (FCSS), these systems will need to operate at much higher speeds and frequencies, have greatly increased functionality, and have much higher levels of integration than present day technology provides. Therefore, fundamental research in the area of Solid State Devices is the corner stone and an essential requirement in the development of these future systems for military defense.

To establish the needed science base for future Army battle-space capabilities, innovative research is sought in the general areas of; novel electronic materials for advanced devices, nanoscale processing and fabrication science, nano/molecular electronic science and technology, nanoscale physical modeling and advanced simulation, ultrafast electronics, advanced device concepts, mixed technologies (electronic, photonic, acoustic & magnetic), heterogenous devices and technologies, micromachined devices and ultra-low-power technologies. Therefore, the program currently emphasizes fundamental research in, (1) Nanoscale Growth and Processing Science, (2) Nanoscale (Semiconductor) Electronics, (3) Molecular Electronics and (4) Advanced Device Concepts, with a focus towards identifying and overcoming existing scientific barriers. Important science and technological barriers include, but are not limited to, the discovery and implementation of new and revolutionary growth techniques for engineering materials and for mixing and matching diverse material systems; the development of novel processing, fabrication and self-assembly techniques for realizing effective integration of diverse materials and devices into